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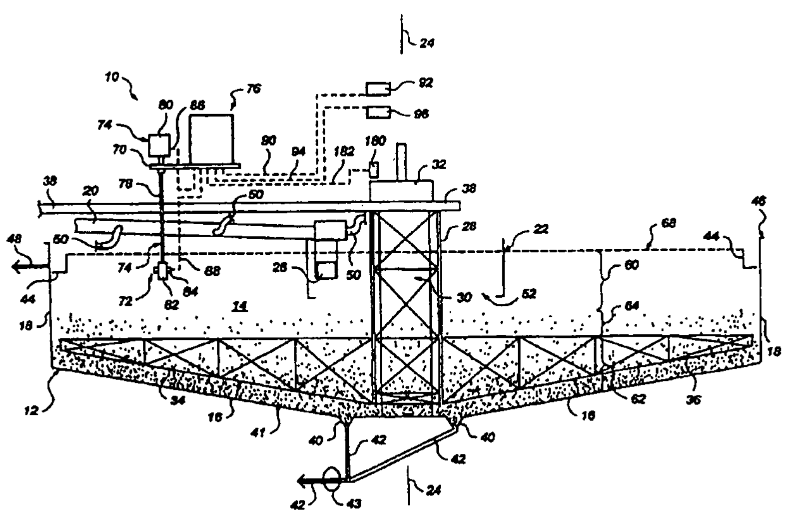

(57) Abstract

An apparatus and method are disclosed for determining the pulp density gradient in a volume of solids-containing fluid processed in a setting tank or thickener tank. The apparatus includes a depth detection device and pressure detection device which provide pressure readings at various depth levels in the fluid volume within the tank. The depth measurements and corresponding pressure measurements at those depths are recorded and calculated by electronic means into a pulp density profile of the fluid volume. The known density profile of a fluid volume, or sludge bed profile, is associated with a solids concentration gradient and facilitates the optimal operation of a settling tank or thickener tank and permits the modification of other operating parameters, such as addition of flocculant, to optimize operation.

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METHOD AND APPARATUS FOR DETERMINING THE PROFILE OF A SLUDGE BED IN A THICKENER

BACKGROUND

Field of the Invention: This invention relates to settling tanks, thickener tanks and similar tank systems used for separating and removing suspended solids from solution, and specifically relates to means for determining the settling efficacy of such tanks by analyzing the sludge bed existing within the tank.

Statement of the Art: Settling tank systems are widely used in a variety of industries to separate solids from solution. As used herein, "solids" denotes suspended solids unless otherwise indicated. Industries in which settling tanks are used include mining industries (for the separation of ore fines and mine waste solids from liquor), wastewater purification systems and chemical processes (where waste or product solids are separated from liquor). Settling tank systems usually include a thickener tank through which solids-containing fluid is processed to remove the solids from the fluid. Thickener tanks include a holding volume into which influent (i.e., solids-containing fluid) is piped, the tank having a sloping bottom surface which directs settling solids toward either a central underflow outlet or a peripherally positioned outlet. A rotating rake assembly slowly moves at least one rake arm along the sloped bottom of the tank to encourage movement of the settled solids toward the underflow outlet. Influent may typically be introduced into a circular tank through a centrally positioned feedwell.

The settling tanks of the type described are configured to promote the gradual settling of solids to the bottom of the tank. A layer of clarified liquid is formed at the top of the tank from the settling of solids therefrom, and the clarified liquid typically exits the tank by overflowing into a weir surrounding the upper periphery of the tank. The configuration and operation of the tank assembly are designed to optimize the settling of solids from the fluid influent by formation of a sludge bed solids concentration profile comprising a clarified

liquid phase, an interface and a sludge bed containing a higher concentration of solids than the fluid influent.

Settling of solids from solution can be optimized further by the addition of flocculating agents to the influent, solids-containing fluid. Flocculating agents provide a surface to which solids adhere and agglomerations of solids result, facilitating the separation of solids from solution. The flocculated solids may then settle to the bottom of the tank more readily. Although flocculants are beneficial at facilitating settling, they are also expensive. Therefore, overuse of flocculating agents in the settling process can increase operation costs unnecessarily. Further, overuse of flocculating agents can result in accelerated settling of solids near the bottom of the tank resulting in solids buildup and eventual clogging. The settling tank must then be taken off-line for cleaning which represents lost productivity and high maintenance expenditures.

It has been recognized in the art that controlling the use of flocculating agents in the settling process is essential to operational efficiency and economics of operation. Thus, various methods have been suggested for evaluating the condition of the settling solids in the tank to determine the need for more or less flocculant addition. Such methods include determining the settling rate of solids in the fluid influent within the tank, and determining the slime level (the interface between the clarified liquid phase and solids-in-solution phase, also referred to as the "sludge level") in the tank as compared to a standard level for optimal operation.

Most of the sludge level detectors used in industry operate on the principles of ultrasound, infrared or visible light. Some employ a float which is configured to float at the supernatant/sludge level interface. These devices are configured for specific applications and are not generally useful over a range of applications. Other devices attempt to determine the slime level by detecting solids concentration in the tank. Such devices are not useful in metallurgical applications given the nature of solids concentrations and the various types of solids which are present in such applications. In addition, most sludge level detectors are subject to increased rates of failure as a result

of clogging from the sludge material in the bed. They require frequent cleaning and maintenance.

While such prior art systems may be helpful in identifying the more efficient use of flocculating agents, the fact remains that the efficient operation of settling tanks is influenced by more than simply the efficient use of flocculating agents. Efficient operation of a settling tank is also influenced, for example, by rake torque and speed, and rate of egress of sludge through the underflow outlet. Determining the slime level in the tank does not provide all the information necessary to determine whether some factor, other than flocculant addition, requires modification in order to increase operation efficiency. Consequently, with many of the methods presently used, additional flocculating agents may be added unnecessarily to the influent responsive to the sludge level analysis when, in fact, some other factor, such as increasing the underflow pump rate, would optimize the thickening process.

Thus, it would be advantageous in the art to provide a means for evaluating the ongoing operation of a settling tank to determine which factors may need modifying in order to provide an optimum condition for operation of the settling tank unit. Providing such means would also enable a more fine-tuned and judicious use of flocculating agents, leading to higher operation efficiency.

SUMMARY OF THE INVENTION

In accordance with the present invention, means are provided for determining the pulp density gradient characteristics of the sludge bed profile in a settling tank system for evaluating the operation of the settling tank, thereby enabling the making of operational modifications to optimize the settling of solids from an influent solids-containing fluid. The present invention may be used to evaluate the sludge bed profile in any type of settling tank/thickener tank unit in any number of industrial applications, but is described hereinafter, by way of example, in terms of use in a settling tank for metallurgical applications. As used herein, the term "sludge bed profile" refers to the pulp density gradient which exists in a thickener tank from the fluid level

near the top of the tank to the bottom of the tank. The term "pulp density," as used herein, is defined as the ratio of the weight of a known volume of a mixture of solids and liquid (a "pulp") to the weight of an equal volume of water; it is typically expressed as specific gravity. The term "pulp density" may be used, therefore, to refer generally to a definition of the liquid/solids mixture as "percent solids." The pulp density gradient corresponds with the suspended solids concentration gradient (i.e., a specific value of solids concentration corresponds to a special value for pulp density for a given specific gravity of dry solids).

A settling tank, or thickener tank, is constructed to receive and process an amount of influent, solids-containing fluid, also referred to herein as "an influent feed stream." The maximum level of fluid processed in the tank is generally dictated by the placement of an overflow weir positioned at or near the top of the tank. In the settling process, a clarified liquid phase is formed at the top of the sludge bed profile from which solids have settled toward the bottom of the tank. At increasing depths of the sludge bed profile, more solids will typically be found in solution until a concentrated solids sludge bed is located in the bottom portion of the tank. An interface is formed between the clarified liquid phase (also referred to as the supernatant) and the solids-containing sludge bed. The interface is also known as the slime level or sludge level.

Ideally, a gradual increase in solids concentration should exist from the interface to the bottom of the tank. A gradual increase in solids concentration relative to depth of the tank is indicative of proper operation of the thickener tank, including proper addition of flocculant. However, a homogeneous concentration of solids in the sludge bed as measured from the interface to the bottom of the tank is indicative of poor tank operation, and possible tank failure. Homogeneous solids concentration in the sludge bed may arise from a variety of factors, including insufficient addition of flocculating agents or a low pumping rate from the underflow outlet (i.e., insufficient rate of removal of sludge at the bottom of the tank).

Additional problems may exist in the thickener tank if the sludge level is too high or too low, a condition which requires detection equally as much as the pulp density gradient in the sludge bed. For example, if the sludge level, or interface, is too high due to improper settling of solids in the sludge bed, solids may be deposited in the overflow weir or entrained in the overflow liquid with deleterious effects on downstream processing. Conversely, a sludge level which is too low could indicate inefficient use of the thickener tank area (i.e., an insufficient amount of influent fluid being processed through the tank) and/or possible overdosing with flocculant. While a low sludge level may not necessarily be associated with improper thickener tank operation, high concentration of solids close to the bottom of the tank may lead to plugging of the underflow pipe, or may cause an increase in the rake torque so that the tank does not operate correctly or efficiently. Under such situations, the thickener tank is usually taken off-line for some time to effect repairs.

The fact that determination of the sludge level alone is inadequate to evaluate proper operation of a thickener tank is illustrated by the following scenario. A metallurgical tailings thickener 30.5 meters (one hundred feet) in diameter is capable of processing a constant mass flow of 27,216 metric tons per day (30,000 stpd (short tons per day)) of solids. The average flocculant addition rate is 0.19 kilograms (0.42 pounds) per minute providing a dosage of 0.009 kilograms (0.02 pounds) of flocculant per metric (short) ton. The underflow solids concentration is 55 wt% and must remain substantially constant (+/- 1 wt%) to maintain optimum downstream process conditions. The pumping rate is 22,483 liters per minute (5,940 gallons per minute (gpm)) and the sludge level is maintained at a controlled depth of about 0.3 meters (one foot), plus or minus 0.15 meters (0.5 feet), as measured from the lowest or bottom point of the upstanding tank wall. At one point in operation, the ore characteristics change over a thirty minute period such that an increase in flocculant addition to 0.025 lbs/st is required to achieve the same settling rate performance. However, the change in solids character is not detected. As a result, the influent feed stream settles more slowly and the sludge level begins

to rise at a rate of 0.635 centimeters (0.25 inches) per minute. A homogeneous solids concentration begins to form in the sludge bed.

Using a known method of sludge level detection, the increase in sludge level could typically trigger an increase in the pumping rate to 27,101 liters per minute (7,160 gpm). The solids concentration at the bottom of the tank would begin to decrease from the required 55 wt%, and an alteration of the sludge bed profile would follow until a new steady state were achieved. A likely response to those conditions would be to increase the addition of flocculant to the influent, but doing so would result in a drop in the sludge level, as well as an increase in solids concentration in the sludge bed. The thickener would not reach a steady state again for some time because the underflocculated material in the thickener would settle and cause the sludge bed to drop rapidly. Thereafter, the underflow pumping rate would be reduced causing the underflow solids concentration to increase until some time after the sludge bed level again reached the control depth and the initial pumping rate of 22,483 liters per minute (5,940 gpm) were achieved. The resulting fluctuation in solids concentration within the sludge bed could result in severe operating problems for the thickener tank and downstream facility. Obviously, knowing the solids concentration profile as determined from the pulp density gradient would facilitate pinpointing the problem and adjusting appropriately to maintain a steady state condition in the thickener tank.

The solids concentration profile of the sludge bed profile is determinable by use of the sludge bed profiler apparatus disclosed herein which measures the hydrostatic pressure at incremental depths below the fluid surface in the thickener tank. Calculation of the differential pressure between corresponding incremental depths in the fluid is then used to produce a pulp density profile of the sludge bed. The corresponding solids concentration profile is calculated directly from the pulp density profile. The profile of the sludge bed, both in terms of positioning of the supernatant/sludge level interface and the pulp density gradient, can be used to evaluate what modifications are necessary to the system to maintain the thickener tank in optimal operation.

The sludge bed profiler disclosed herein generally includes a pressure detection device connected to a depth measurement device, and electronic means associated with the pressure detection device and depth measurement device for transmitting information relating to pressure and depth for recording and calculation of the pulp density gradient in the sludge bed. Programmed calculation means record and calculate the information to determine the sludge bed profile.

The depth measurement device of the sludge bed profiler apparatus may be any suitable structure which exists in, or extends vertically into, the fluid volume within the tank. The depth measurement device may be permanently positioned within the tank or may be temporarily lowered into the tank for a period sufficient to take pressure readings of the fluid volume along a vertical axis from the top of the fluid volume to the bottom. The pressure detection device is structured to operate within the fluid volume in the tank, relative to the depth measurement device, to sense the hydrostatic pressure in the fluid at any depth within the fluid volume. The pressure detection device may be any suitable structure which is capable of sensing pressures, such as a pressure transducer.

A programmable data recording device, such as a computer with appropriate software, is used to collect the data received from the pressure detection device and the depth detection device. The programmable device calculates the differentials between sequential data pairs of pressure and corresponding depth, and converts that information into a pulp density profile of the fluid volume. The pulp density profile of the fluid volume may then be converted to a solids concentration profile of the fluid volume based on the known specific gravities of the solids in solution and the liquid. Based upon the sludge bed profile data calculated by the programmable device, a programmed or manual analysis of the profile can be conducted to determine what modifications in thickener tank operation should be taken. That information can be further relayed to a central control unit which is then responsible for taking an appropriate action, such as increasing the underflow pump speed. The sludge bed profiler apparatus may also be interfaced with

various operation elements of the settling tank, such as the underflow pump or flocculant addition controller, to automatically modify the system's operation.

The sludge bed profiler of the present invention can be used singly with the settling tank, or thickener tank, in many industrial applications, or it may be integrated with a thickener control unit to enhance the ability of the thickener control unit to select the appropriate amount of flocculant to be added to the settling or thickener tank, or to optimize the underflow pumping rate.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, which currently illustrate what is considered to be the best mode for carrying out the invention,

FIG. 1 is a representation of a thickener tank having a sludge bed profiler apparatus attached thereto;

FIG. 2 is an enlarged view of the sludge bed profiler apparatus shown in FIG. 1;

FIG. 3 is a representation of the mechanism of the depth detection control mechanism of the sludge bed profile apparatus shown in FIG. 2;

FIG. 4 is a representation of the mechanical reeling mechanism of the depth detection control mechanism illustrated in FIG. 3;

FIG. 5 is a representation of a control console of the sludge bed profiler apparatus shown in FIG. 2; and

FIGS. 6-8 are graphs illustrating pulp density values determined by the sludge bed profiler apparatus as compared to pulp density determinations made manually.

DETAILED DESCRIPTION OF THE DRAWINGS

The sludge bed profiler apparatus 10 is represented in FIG. 1 in connection with a thickener tank 12. The thickener tank 12 generally comprises a volume 14 enclosed by a tank bottom 16 and side wall 18 which is connected to the tank bottom 16. The thickener tank 12 is sized and configured for receiving solids-containing influent feed from an influent feed pipe 20. As illustrated in FIG. 1, influent feed is directed into a feedwell 22

which is positioned concentrically with the central axis 24 of the thickener tank 12. A distribution box 26 may be associated with the influent feed pipe to deliver influent feed to the feedwell 22.

A central column 28 positioned concentrically with the thickener tank 12 supports a rake assembly 30 which rotates by a rake drive mechanism 32 to turn the rake arms 34, 36 positioned near the bottom 16 of the thickener tank 12. A walkway 38 may also be supported above the thickener tank 12 by attachment to the central column 28. The walkway 38 extends from the center of the thickener tank 12 to a point beyond the side wall 18 of the thickener tank 12 where access to the walkway 38 is available for workmen.

The thickener tank 12 is constructed with at least one underflow outlet 40 (illustrated in FIG. 1 as having two underflow outlets) into which settled solids, or sludge, at the bottom 16 of the thickener tank 12 is collected by rotation of the rake arms 34, 36. Sludge entering into the underflow outlet 40 is carried away from the thickener tank 12 via sludge pipes 42 interconnected to the underflow outlet 40. Removal of sludge from the underflow outlet 40 may be facilitated by operation of a underflow pump 43 associated with the sludge pipes 42. The thickener tank 12 also includes an overflow weir 44 positioned at the top 46 of the tank which may generally encircle the thickener tank 12. The overflow weir is positioned to collect clarified liquid which forms near the top 46 of the thickener tank 12 during the settling process. Clarified liquid is removed from the overflow weir 44 via an overflow outlet pipe 48 connected to the overflow weir 44.

In the settling process, influent feed enters into the feedwell 22 from the influent feed pipe 20 and distribution box 26. As influent feed moves through the influent feed pipe 20, flocculating agents may be added through one or more flocculant feed pipes 50 interconnected with the influent feed pipe 20. The feedwell 22 operates to equalize distribution of the influent feed into the thickener tank 12 and to reduce or dissipate flow turbulence in the influent feed which would otherwise disrupt the settling process occurring in the thickener tank 12. Influent feed exits the feedwell through the open bottom 52 of the feedwell 22 to enter into the volume 14 of the thickener tank 12. As the

influent feed remains in the thickener tank 12, the solids within the influent feed begin to settle out and accumulate at the bottom 16 of the thickener tank 12. Flocculation of the solids assists in settling of the solids. Rotation of the rake arms 34, 36 also assists in the settling of solids from solution and moves the accumulated solids, or sludge, toward the underflow outlet 40.

Notably, the rake arms 34, 36 do not scrape the surface of the bottom 16 of the thickener tank 12. Rather, the rake assembly 30 is installed so that the rake arms 34, 36 are positioned a small distance (e.g., 2.5 centimeters (one inch)) above the surface of the bottom 16 of the thickener tank 12. A thickness of solids accumulates on the bottom 16 of the thickener tank 12 and the rake arms 34, 36 skim the thickness of accumulated solids to produce what is termed a "raked surface" 41.

As shown representationally in FIG. 1, three general phases form in the fluid contained in the thickener tank 12 as the solids settle out of the influent feed. That is, a clarified liquid phase 60 forms near the top 46 of the thickener tank 12, a layer of accumulating solids of ever-increasing concentration forms toward the bottom 16 of the thickener tank 12, designated as the sludge bed phase 62, and an interface 64 exists between the clarified liquid phase 60 and the sludge bed phase 62. The interface 64 may contain some solids in solution, but the concentration of solids in the interface 64 is lower in comparison with the sludge bed phase 62. For the purposes of this disclosure, the "sludge bed profile" may be considered to include all three phases (clarified liquid phase 60, sludge bed phase 62 and interface 64) formed in the thickener tank 12.

Ideally, the pulp density (i.e., solids concentration) within the sludge bed profile will gradually increase from the interface 64 down through the sludge bed phase 62 to the bottom 16 of the thickener tank 12 as settling progresses. Vertical positioning of the interface 64 which forms within the thickener tank 12 may vary, but ideally may be positioned (i.e., formed) well below the overflow weir 44 and within the bottom third of the fluid depth, as measured from the bottom of the tank sidewall 18. The interface 64 is illustrated in FIG. 1 as being positioned vertically at about the midpoint of the thickener tank 12. If

the thickener tank 12 is not operating under ideal conditions (e.g., the settling of solids is too slow or too rapid, or the type of solids in the influent feed has changed), there will not be a gradual increase of pulp density in the sludge bed profile. Rather, it is possible that the concentration of solids at the interface 64 will be almost as great as the concentration of solids near the raked surface 41. In addition, the interface 64 may exist very near the fluid level 68 in the tank such that solids may overflow into the overflow weir 44, or the interface 64 may exist closer to the bottom 16 of the thickener tank 12 indicative of inefficient use of flocculating agents.

Shifts in the pulp density (i.e., solids concentration) gradient and the positioning of the interface 64 in the tank may be due to several factors, including addition of too much or too little flocculant, increased solids content in the influent feed stream, a change in the type of solids contained in the influent feed stream, a change in the flow rate of influent feed into the thickener tank 12 or a change in the underflow pumping rate. The pulp density gradient and position of the interface 64 in the thickener tank 12 may be modified to bring the thickener tank 12 into ideal operating conditions by implementation of any of several techniques, including increasing or decreasing the addition of flocculants, or increasing or decreasing the underflow pumping rate to alter removal of sludge from the underflow outlet 40.

The ability to take corrective steps to bring the thickener tank 12 into ideal operating conditions is facilitated by the sludge bed profiler apparatus 10 associated with the thickener tank 12. The sludge bed profiler apparatus 10 may be conveniently positioned on, or connected to, the walkway 38, or otherwise positioned on a platform 70 above the thickener tank 12 anywhere along the radius. However, the sludge bed profiler apparatus 10 may be most suitably located at a distance of about one third to about two thirds the radius dimension of the thickener tank 12 as measured from the side wall 18 of the thickener tank 12. The sludge bed profiler apparatus 10 should be positioned at a distance from the feedwell 22 to avoid aberrant pressure measurements which may be caused by fluid turbulence in proximity to the feedwell 22. The sludge bed profiler apparatus 10 measures the pulp density profile of the fluid

in the thickener tank 12 from near the fluid level 68 (i.e., the clarified phase) to the raked surface 41, and indicates where the interface 64 is located in relative vertical position within the tank 12. The sludge bed profiler apparatus 10 generally comprises a pressure detection device 72, a depth measurement device 74 and an electronic recording and calculating device 76 for recording and calculating information obtained from the pressure detection device 72 and depth measurement device 74.

In one exemplar embodiment of the invention, as illustrated in FIG. 1, the sludge bed profiler apparatus 10 is positioned on a platform 70 located relative to the walkway 38. The depth measurement device 74 comprises an extension cable 78 emerging from a reeling mechanism housing 80 which is, in turn, attached to the platform 70. The extension cable 78 is oriented to extend vertically into the volume 14 within the thickener tank 12. A weight 82 is connected to the lower end of the extension cable 78. The extension cable 78 is reeled out from the reeling mechanism housing 80 to lower the weight 82 a selected depth into the volume 14 of the thickener tank 12. The pressure detection device 72 comprises a pressure transducer 84 which is attached to the weight 82 in a manner which allows the pressure transducer 84 to travel from the top of the volume 14 to the raked surface 41 to measure the hydrostatic pressure through the vertical depth of the sludge bed profile.

An electronic connection 86 between the reeling mechanism housing 80 and the electronic recording and calculating device 76 transmits to the latter information relating to the depth the extension cable 78 has moved during a measuring cycle. An electronic connection 88 between the pressure transducer 84 and the electronic recording and calculating device 76 transmits to the latter information relating to the hydrostatic pressure detected at various levels through the vertical depth of the volume 14. As described further hereinafter, the calculations derived from the depth and pressure data transmitted from the pressure transducer 84 and the reeling mechanism housing 80 may be communicated by transmission line 90 to a modem 92 which is in communication with a central processing locale (not shown). The

sludge bed profiler apparatus 10 is generally powered by connection 94 to a power source 96, such as a 120 VAC source.

The mechanism of the sludge bed profiler apparatus 10 is shown in greater detail in FIG. 2 which illustrates the electronic recording and calculating device 76 and reeling mechanism housing 80 positioned atop the platform 70 and oriented above the fluid level 68 in the thickener tank 12. The extension cable 78 which emerges from the reeling mechanism housing 80 is shown to be interconnected between and attached to an upper weight 98 and the weight 82 to which the pressure transducer 84 is attached. The upper weight 98 serves as a stopping mechanism when the extension cable 78 is being retracted out of the fluid at the end of a measuring cycle, as explained more fully hereinafter. The distance 100 between the upper weight 98 and the weight 82 attached to the pressure transducer 84 is sufficient to maintain the weight 82 below the fluid level 68 of the fluid in the thickener tank 12 at all times. Additionally, as shown in the embodiment illustrated in FIG. 1, the distance 100 between the upper weight 98 and weight 82 connected to the transducer 84 may be approximately equal to the depth of the sludge bed profile (i.e., depth of fluid in the tank 12) so that when the weight 82 reaches the raked surface 41, the upper weight 98 will be positioned approximately at the fluid level 68. Accordingly, the length of cable, designated as the reeling cable 79, above the upper weight 98 does not come in contact with the fluid in the thickener tank 12 and there is no likelihood that solid matter adhering to the extension cable 78 will be retracted into the reeling mechanism. Alternatively, cable drum housings which are structured to prevent the deposit of material in the reeling mechanism may be particularly suitable for use in the sludge bed profiler apparatus 10 to enable positioning of the reeling mechanism closer to the top of the tank 12.

The weight 82 is generally positioned so that the pressure transducer 84 connected to the weight 82 is positioned a selected distance 102 below the fluid level 68. The selected distance 102 preferably may be approximately 12 centimeters (five inches). The weight 82 will, therefore, remain submerged at all times and will begin and end each measuring cycle at the selected distance

102 below the fluid level 68. The weight 82 may also include a lowermost point 104 which is positioned to contact the raked surface 41 during a measuring cycle. To facilitate the descent of the extension cable 78 into the fluid, the weight measurement of the weight 82 should be sufficient to move the pressure transducer 84 through the fluid. The weight measurement of the weight 82 is dependent, therefore, upon the nature of the influent feed and the solids content thereof. A suitable weight 82 for use with mine tailings, for example, may be about 1.9 kilograms (4.2 pounds).

As seen in FIG. 2, the pressure transducer 84 is connected to the weight 82 in a manner which orients the face 106 of the pressure transducer 84 generally parallel to the extension cable 78 and vertically within the fluid volume. Although orienting the face 106 of the pressure transducer 84 vertically within the fluid volume may produce the best reading results, the angle of the face 106 of the pressure transducer 84 may vary from strictly a parallel orientation and still correctly measure the hydrostatic pressure of the sludge bed profile. Further, although many suitable pressure transducers are available on the market for use in the sludge bed profiler apparatus 10, those which have a larger face 106 are most suitable for use in high solids concentration environments because the face 106 of the pressure transducer 84 is less likely to become clogged or impaired by sludge material attaching to the face 106. It has been shown, however, that a small buildup of fine solids on the face 106 of the pressure transducer 84 does not adversely affect the ability of the transducer 84 to operate accurately. Additionally, the face 106 of the pressure transducer 84 may be easily and quickly cleaned if necessary. Preferably, the pressure transducer 84 is operational at a pH range of 1.0 to 14.0, a temperature range of 1°C. (35°F.) to 82°C. (180°F.), and at a solids concentration of from about 0.01 wt.% to about 70.0 wt.%.

The electronic connection 88 between the electronic recording and calculating device 76 and the pressure transducer 84 is preferably maintained in close proximity to the extension cable 78 during descent of the extension cable 78 into the fluid in the tank 12. The extension cable 78 and electronic connection 88 may be secured together by attachment means 108 which

allows the electronic connection 88 to move with the extension cable 78. As illustrated in FIG. 2, enough excess length (footage) of the electronic connection 88 exists to extend a depth equal to the extension cable 78 when the weight 82 descends to the bottom 16 of the thickener tank 12. Alternatively, the extension cable 78 may be integrally formed with the electronic connection 88 within a coaxial cable.

The function of the depth detection device 74 is controlled within the reeling mechanism housing 80 by an electromechanical reeling mechanism 110 as shown in FIGS. 3-4. Electromechanical reeling mechanisms are generally known and available with various elements selected for operation in a particular application. One example of an electromechanical reeling mechanism, one which is designed for measurement of dry bulk in silos, is the CM3A manufactured by Monitor Manufacturing of Elburn, Illinois. The principal electrical elements of the electromechanical reeling mechanism 110 used in the instant application are shown in FIG. 3 and the principal mechanical elements of the electromechanical reeling mechanism 110 are shown in FIG. 4.

Fundamentally, the electrical elements of the electromechanical reeling mechanism 110 include a cable reel motor 112 which operates to reel out and retract the reeling cable 79 within the reeling mechanism housing 80, a counter 114 which is selected to mark out incremental depths to which the pressure detection device 72 descends as a result of the movement of the reeling cable 79, a motor control relay 116 which controls the functions of the various components, a motor control capacitor 118 and an interconnection terminal bank 120. The electromechanical reeling mechanism 110 may also include a rotary actuator 122 which is positioned to actuate a number of switches, including a shutoff switch 124, a reversing switch 126, a cycle light switch 128 and a cycle interlock switch 130. A second terminal bank 132 may be included for attaching external electronic connections (e.g., to a proximity switch device 180 for initiating operation of the reeling mechanism) to the reeling mechanism housing, and a manual switch 134 may be provided for activating the cable reel motor 112 in emergency situations.

As shown in FIG. 4, a winding pulley and spool 138 is provided for maintaining the reeling cable 79 which is interconnected between the winding pulley and spool 138 and the upper weight 98. The winding pulley and spool 138 is caused to rotate, in both a forward and backward direction, by the cable reel motor 112. The reeling cable 79 winds about an idler pulley 140 and a counter pulley 142, the latter being connected to the counter 114. The reeling cable 79 also winds through a spring-loaded reversing gear 144, connected to the rotatory actuator 122, which functions to sense when a slack occurs in the reeling cable 79, indicative of when the weight 82 reaches the raked surface 41, and causes the cable reel motor 112 to switch into reverse mode. The electromechanical reeling mechanism 110 may also include a cable break switch 146 which signals the cable reel motor 112 to stop if a break in the reeling cable 79 occurs. The reeling mechanism housing 80 may also include a standpipe 148 through which the reeling cable 79 moves, as shown in FIGS. 3 and 4.

The electronic recording and calculating device 76 of the sludge bed profiler apparatus 10 is illustrated in FIG. 5 and generally includes a housing 150 into which a central processing unit 152 (CPU) with an additional interface structure 153 (as required by the program software), a monitor 154 and a keyboard 156 may be placed. A programmable logic computer (PLC) which has a CPU and built in interface can be used alternatively. The housing 150 is constructed with an electrical connector bank 158 through which various electronic connections may be positioned (e.g., electronic connections 90 and 94). A heater unit 160 may preferably be provided in the housing 150 to keep the computer equipment at operational temperature (i.e., 1°C. (35°F.) or above) during the winter. A first relay board 162 and second relay board 164 are provided for external component interconnection and interfacing. A modem connection 166 provides means for interconnecting the CPU 152 with external processing units or transmission pathways (e.g., central data processing unit or LAN connection). A time delay relay 168 is interconnected to the electromechanical reeling mechanism 110 to prevent premature lowering of the pressure detection device 72 upon power-up. A 12 VDC power supply

source 170 is provided in the housing 150 to supply power to the first relay board 162 and the second relay board 164, and to the interface structure 153 (which supplies power to the pressure transducer 84). A bank of 110 VAC outlets 172 is also provided for plugging the monitor 154 and CPU 152 into an externally supplied 110 VAC power source 96.

The sludge bed profiler apparatus 10 may be configured or programmed to operate at least twice within a full rotation of the rake assembly 30. That is, as one rake arm 34 passes a designated point relative to the position of the sludge bed profiler apparatus 10, a proximity switch device 180 (FIGS. 1 and 2) located on or near the rake drive mechanism 32 signals the CPU 152 via a proximity switch electronic connector 182 that the measuring cycle may begin. As shown in FIG. 2, the proximity switch device 180 may comprise a trip plate 184 which is aligned with each rake arm 34, 36 and a magnetically operated proximity switch 186 which is tripped as a trip plate 184 associated with a rake arm 34 goes by. The proximity switch 186 then sends an electrical signal to the CPU 152 which, in turn, signals the cable reel motor 112 via electronic connection 86 to begin reeling out reeling cable 79 from the winding pulley and spool 138. The CPU 152 also initiates a measuring cycle program which is displayed on the monitor 154. The distance 102 at which the pressure transducer 84 remains submerged (e.g., 12 centimeters (five inches) below the fluid level 68) is the default starting depth of the measuring cycle.

In one embodiment, the measuring cycle program signals the cable reel motor 112 to power on for a selected time (e.g., about one second) to cause the winding pulley and reel 138 to rotate and release, or reel out, a selected length of reeling cable 79 therefrom. The counter 114, which is shown in FIG. 3 to be a cog-wheel type structure, may mark out incremental units corresponding to a selected length of reeling cable 79 as the counter 114 rotates. The incremental units marked out during a selected time that the cable reel motor 112 is powered on is relayed to the CPU 152 and the measuring cycle program records the number of incremental units marked out. The number of incremental units marked out can then be associated with the distance the pressure detection device 72 has moved or been lowered into the

fluid within the thickener tank 12. As will be apparent to those skilled in the art, these time intervals can be changed, and a larger or smaller number of pressure readings could be accumulated appropriate to the embodiment. These time intervals are for illustration only. For example, if the measuring cycle program is calibrated to equate 1,640 (500) incremental units per meter (foot), and the counter 114 marks out 279 (270) incremental units, then the measuring cycle program denotes a measured movement of 0.17 meters (0.55 feet) in the extension cable 78, and hence the pressure detection device 72. In one particularly suitable embodiment, the counter 114 may be an optical counter which similarly sends a signal to the measuring cycle program.

The measuring cycle program may be programmed to cause the cable reel motor 112 to power on for any selected amount of time suitable to the particular application. In a thickener tank 12 for processing metallurgical tailings, for example, the measuring cycle program may be programmed to signal the cable reel motor 112 to run a sufficient amount of time to approximate a number of incremental units, metered out by the counter 114, to equal a descent of about 0.17 meters (0.55 feet) of the pressure detection device 72 into the fluid in the thickener tank 12. After the cable reel motor 112 has run for the selected amount of time programmed by the measuring cycle program to mark out the selected number of incremental units, the measuring cycle program signals the cable reel motor 112 to pause, or power down, for a selected time so that the pressure transducer 84 can take one or more readings at that depth of the sludge bed profile.

In a preferred program, the cable reel motor 112 is programmed to idle for a ten second period of time at each 0.17 meter (0.55 foot) descent of the pressure detection device 72 into the sludge bed profile. During that ten second idle, the pressure transducer 84 takes hydrostatic pressure readings at half second intervals. Therefore, at each incremental stop, twenty-one pressure readings are taken by the pressure transducer 84 at a given depth, and the twenty-one pressure readings are each relayed via electronic connection 88 to the CPU 152. After the ten second pause, the cable reel motor 112 is initiated to power on again for the selected time programmed, and

the counter 114 marks out another selected number of incremental units corresponding to approximately 0.17 meter (0.55 foot) length of reeling cable 79 to be reeled out. The cable reel motor 112 then idles again for a ten second period. Pressure readings are taken by the pressure transducer 84 at half second intervals at the new depth and that data is transmitted to the CPU 152, and so on.

In a thickener tank 12 which, for example, measures 4.1 meters (13.5 feet) from the fluid level 68 to the raked surface 41 at the position of the sludge bed profiler apparatus 10 relative to the radius of the thickener tank 12, the pressure transducer 84 will make twenty-four stops at intervals of 0.17 meters (0.55 feet) and will pause for ten seconds at each stop. If the cable reel motor speed operates at 0.46 meters (1.5 feet) per second, the total descent time of the transducer in a measurement cycle is approximately five minutes. When the lowermost point 104 of the weight 82 reaches the raked surface 41 of the thickener tank 12, the extension cable 78, and thus the reeling cable 79, will become slack which triggers the spring-loaded reversing gear 144 to signal the cable reel motor 112 to reverse direction. The reeling cable 79 is continuously retracted into the reeling mechanism housing 80 and only stops when the upper weight 98 reaches the bottom of the standpipe 148. The cable reel motor 112 stops and the measuring cycle program reinitializes.

The passage of the next rake arm 36 triggers the proximity switch 180 and another measuring cycle is initiated. The rotation rate of the rake assembly 30 differs between settling tank configurations and the operational conditions or parameters. That is, for example, a complete 360 degree rotation of a rake assembly 30 may be forty minutes. Thus, each new measuring cycle is initiated at about twenty minute intervals (as the two rake arms trigger the proximity switch 180). More frequent measurement cycles may be programmed within the period of rotation of the rake assembly 30. Further, rake assemblies which comprise more than two rake arms (e.g., four rake arms) will require programming of the measuring cycle program to accommodate measuring between the passage of each rake arm or, if desirable, between passage of every other rake arm.

Because the sludge bed profiler apparatus 10 must be timed to initiate and complete at least one measurement cycle between the rotation of the rake arms, a time delay may be programmed into the operation of the sludge bed profiler apparatus 10 which prevents premature descent of the pressure detection device 72 until after a rake arm 34, 36 has passed. Thus, for example, the computer may be programmed to initiate a time delay at the power up of the system or at the end of a measuring cycle to prevent the descent of the pressure detection device 72 for an amount of minutes or seconds corresponding to an assured time when the rake arm has passed. Further, the program may include a descent timer which will automatically operate to raise the pressure detection device 72 if a certain amount of time has passed exceeding the normal measuring cycle. Therefore, if the pressure detection device 72, weight 82 or extension cable 78 should become snared on something in the tank 12, the cable reel motor 112 will power up to raise the pressure detection device 72 before the rake arm 34, 36 passes by.

The CPU 152 of the electronic recording and calculating device 76 is programmed with suitable software to receive and record data relating to the incremental depths at which the pressure transducer 84 takes pressure readings, and to receive and record the pressure readings made by the pressure transducer 84. A spreadsheet software program (e.g., Quattro Pro® or Lotus 1-2-3®) may be particularly suitable for use in the present invention. Upon initiation of a measuring cycle, the computer program defaults to the selected distance 102 below the fluid level 68 at which the pressure transducer 84 is submerged. The first readings of the pressure transducer 84, upon initiation of the measuring cycle, are taken at that selected distance 102 where the pressure transducer 84 is submerged below the fluid level 68. Notably, an initial pressure reading is taken at atmospheric pressure, as measured by the pressure transducer 84 before the pressure transducer 84 is submerged in the fluid within the thickener tank 12, and the initial pressure is stored in the program for calibration purposes. The measurement of atmospheric pressure is only required when a transducer is first put on line, after replacement or following routine maintenance (i.e., cleaning).

As the pressure detection device 72 descends a selected distance (e.g., 0.17 meters (0.55 feet)) into the fluid, the relay 116 signals the CPU 152 that a new depth measurement interval has been reached and that new depth is recorded by the program. The pressure transducer 84 takes multiple pressure readings at that depth measurement and the data relating to those pressure readings is transmitted to the CPU 152. The pressure readings taken at any single depth of the sludge bed profile are recorded by the computer and are then averaged to provide an average pressure reading at a given depth measurement. The values are mathematically averaged using, for example, the calculation (0.8 x old average) + (0.2 x new input value) = new average.

The program records pairs of data corresponding to a depth measurement and the average pressure reading at that depth. The pulp density at any given depth is calculated by the following formula:

$$(K)(P_2 - P_1)/(D_2 - D_1) = \text{density at } (D_1 + D_2)/2$$

where P is pressure, D is depth and K is a constant to convert to specific gravity units. The solids concentration at each depth measurement of the sludge bed profile is then determined from the calculated pulp density using known values for the specific gravity of the solids and the liquid, employing the following formula:

$$Concentration = \frac{(SG_L)(SG_S) - (d)(SG_S)}{(d)(SG_L) - (d)(SG_S)}$$

where SG_L is the specific gravity of the liquid, SG_S is the specific gravity of the solids and d is the pulp density value at any given depth.

The graphs of FIGS. 6-8 illustrate the pulp density gradient evaluations for a 122 meter (400 foot) diameter thickener tank which was used to process copper mine tailings. The thickener tank processed approximately 554 kilograms per second (2200 stph (short tons per hour)) of influent feed with a calculated solids concentration of 22 wt.%. The underflow concentration ranged from about 38 wt.% to about 42 wt.% with a solids specific gravity of about 2.7 and a liquid specific gravity of about 1.003. The circuit pH was kept at about 8.0. Flocculant was added to the influent feed at a dosage of about

0.035 kilograms per metric ton (0.07 pounds per ton) of solids. The fluid depth in the thickener tank was about 4.1 meters (thirteen and one half feet) at the sludge bed profiler apparatus location (i.e., one half the radius of the thickener tank 12). The pulp density gradient of the sludge bed profile was determined by the sludge bed profiler apparatus disclosed herein.

The sludge bed profile was also manually evaluated using a "bacon bomb" sampling device consisting of a small cylinder having a manually operated filling valve. The bacon bomb cylinder was lowered to a known depth in the fluid within the tank, the filling valve was opened allowing the cylinder to fill with a sample of fluid and the cylinder was then retrieved and evaluated. The specific gravities of the solid and liquid were determined and the solids concentration measured from the samples obtained at each depth tested. From those data, the corresponding values for pulp density were calculated. Manual testing by the bacon bomb method took about twenty-five minutes to complete and did not involve taking samples at all of the depths measured by the sludge bed profiler apparatus. Generally, manual measurements were taken at 0.3 meter (one foot) intervals while the sludge bed profiler apparatus took measurements at intervals of 0.17 meter (0.55 feet).

The pulp density profile developed from the manual sampling was plotted against the pulp density values derived from the sludge bed profiler apparatus as shown in FIGS. 6-8. Values derived by the sludge bed profiler are denoted with an "x" and the values derived from the manual sampling are denoted with the symbol "+." It can be seen that the data provided by the sludge bed profiler was consistent with the data derived from the manual sampling. The graphs of FIGS. 6-8 also provide a visual representation of the pulp density profile of the sludge bed profile at each measurement cycle and an indication of where the interface is formed in the sludge bed profile (determined by observing at which point the pulp density increases beyond the pulp density indicated for the upper portion of the sludge bed profile). FIG. 6 illustrates a graduated pulp density profile beginning at a depth of about 3.2 meters (10.5 feet), with an interface, or sludge level, being formed at a depth of about 3 meters (10 feet). FIG. 7 illustrates a more smooth pulp density

gradient beginning at a depth of about 2.4 meters (8 feet) with an interface formed at about 2.3 meters (7.5 feet). FIG. 8 illustrates a sharper interface formed at a depth of about 2 meters (6.5 feet), with a less gradual pulp density gradient existing between a depth of 2.1 meters (7 feet) and the bottom of the tank.

The sludge bed profiler apparatus 10 may also be configured and programmed to move the pressure detection device 72 through the sludge bed profile continuously without stopping at intermittent intervals as previously described. Continuous movement of the pressure transducer 84 is achievable by slowing the cable reel motor 112 speed to about 0.03 to 0.15 meters (0.1 to 0.5 feet) per second. At that speed, the pressure transducer 84 may take continuous and accurate hydrostatic pressure readings at every increment of depth throughout the profile. The ultimate speed of the cable reel motor 112, however, will be dependent upon the rotation rate of the rake assembly 30 since at least one measurement cycle must be initiated and completed between the rotation of the rake arms. An increase in the number of data pairs (pressure/depth readings) that can be accepted and recorded by the measuring cycle program enables the production of a smoother pulp density profile representation as the pressure detection device 72 descends into the fluid volume because more data is available.

The sludge bed profiler apparatus 10 (i.e., the electronic recording and calculating device 76) may be directly interfaced with various operational elements of a settling tank or thickener tank to control and/or modify the operation of those elements responsive to the pulp density (i.e., solids concentration) gradient associated with the sludge bed profile. For example, the sludge bed profiler apparatus 10 may be electronically interfaced with a flocculant metering pump (or metering device) associated with the tank to increase or decrease the addition of flocculant to the influent feed responsive to an indication from the pulp density gradient associated with the sludge bed profile that more or less flocculant is required to produce a more gradual pulp density gradient. Similarly, the sludge bed profiler apparatus 10 may be

electronically interfaced with the underflow withdrawal system to increase or decrease removal of the underflow from the system.

The sludge bed profiler apparatus 10 associated with any one settling tank may be placed in communication with a central control unit for monitoring along with several other sludge bed profiler apparatus installed in settling tanks in industries where a number of settling tanks or thickener tanks are operated simultaneously. The sludge bed profiler apparatus 10 may also be placed in communication with a remote site, away from the settling tank or plant operations, enabling monitoring or control of the settling tank operations at a distance. A remote communications link permits the monitoring and control of more than one settling tank and more than one plant site.

The apparatus and method of determining the pulp density gradient (i.e., solids concentration) in a settling tank or thickener tank described herein comprises the evaluation of hydrostatic pressure at various depths in a fluid volume contained in the settling or thickener tank and calculating from that data a solids concentration profile of the fluid volume. The sludge bed profiler apparatus and method described herein may be used in any tank system used to settle or separate solids from solution in an influent feed stream and is not limited in its use to the tank dimensions or configuration described herein. For example, the sludge bed profiler apparatus of the present invention may be used for the accounting of solids weight for metallurgical balance, especially as applied to concentrate thickeners. Thus, reference herein to specific details of the illustrated embodiments is merely by way of example and not by way of limitation. It will be apparent to those skilled in the art that many modifications of the basic illustrated embodiment may be made without departing from the spirit and scope of the invention as recited by the claims.

CLAIMS

What is claimed is:

1. Apparatus for determining the pulp density gradient in a volume of fluid containing solids comprising:

a depth detection device;

a pressure detection device connected to said depth detection device; and

an electronic recording and calculating device in electrical communication with said depth detection device and said pressure detection device for recording data relating to fluid depths and to hydrostatic pressures at said fluid depths, and converting said data into a pulp density gradient profile of a fluid volume.

2. The apparatus of claim 1 wherein said pressure detection device comprises a pressure transducer, an extension cable having a length extendable into a fluid volume, and a weight attached to said extension cable, said pressure transducer being connected to said weight.

3. The apparatus of claim 2 wherein said depth detection device further includes a reversible motor connected to said extension cable for extending or retracting said length of extension cable, with said reversible motor structured to stop intermittently corresponding to selected depths.

4. The apparatus of claim 1 wherein said electronic recording and calculating device includes a programmable central processing unit, a reversible reeling motor and an extension cable, said reversible reeling motor being in electrical communication with said central processing unit.

5. The apparatus of claim 4 wherein said pressure detection device comprises a pressure transducer in electrical communication with said central processing unit to transmit data thereto, with said reversible reeling motor being configured to stop intermittently responsive to an electrical signal received from said central processing unit.

6. A settling tank for processing solids-containing fluid comprising:

a tank having a bottom, sides and a central axis, and sized to retain a volume of fluid;

an influent feed pipe positioned to deliver an influent feed stream into said tank;

an underflow outlet positioned near said bottom of said tank;

an overflow outlet connected to said tank; and

a sludge bed profiler apparatus having a depth detection device and pressure detection device for determining the pulp density gradient of fluid within said tank, said sludge bed profiler being oriented relative to said tank to measure depths and pressures of said volume of fluid.

7. The settling tank of claim 6 wherein said sludge bed profiler apparatus further includes an electronic recording and calculating device in electrical communication with said pressure detection device and said depth detection device for recording data relating to depth measurements and pressure measurements taken at said depth measurements, wherein said depth detection device includes an extension cable and reversible motorized reeling mechanism for extending said extension cable into said fluid within said tank, and wherein said pressure detection device comprises a pressure transducer attached to said extension cable.

8. The settling tank of claim 7 wherein said electronic recording and calculating device includes a programmable central processing unit in electrical communication with said reversible motorized reeling mechanism, said central processing unit being programmed to actuate said reversible motorized reeling mechanism to extend said extension cable into said fluid within said tank.

9. A method for determining the pulp density gradient profile of a fluid volume comprising:

providing a depth detection device, a pressure detection device connected to said depth detection device and an electronic recording and calculating device in electrical communication with said depth detection device and said pressure detection device for recording data relating to fluid depths and hydrostatic pressures at said fluid depths;

taking a plurality of depth measurements of a volume of fluid;

taking at least one fluid pressure reading corresponding to each of said plurality of depth measurements;

relaying said depth measurements and said pressure readings to said electronic recording and calculating device;

calculating the differentials between two depth measurements and corresponding pressure measurements at said two depth measurements to determine the pulp density data at any given depth of said volume; and

converting said pulp density data into a solids concentration profile of said volume by applying to said pulp density data known specific gravity values for the liquid content and solids content of said fluid.

10. The method according to claim 9 wherein said plurality of depth measurements are taken intermittently at selected depths of said volume.

11. The method according to claim 10 wherein a plurality of fluid pressure measurements are taken at each said plurality of depth measurements and pressure measurements are mathematically averaged to achieve an average pressure measurement for each said plurality of depth measurements.

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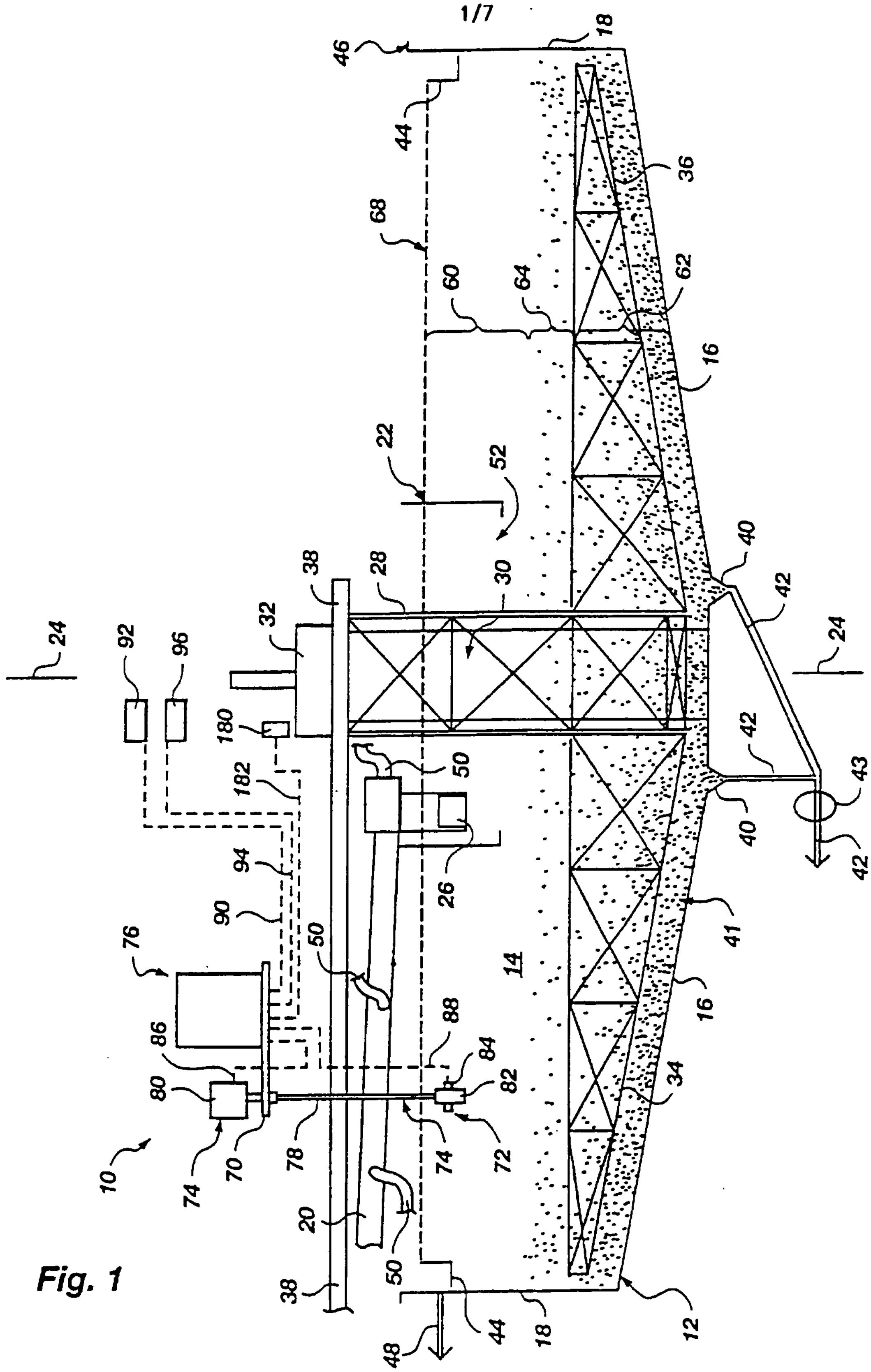

Fig. 1

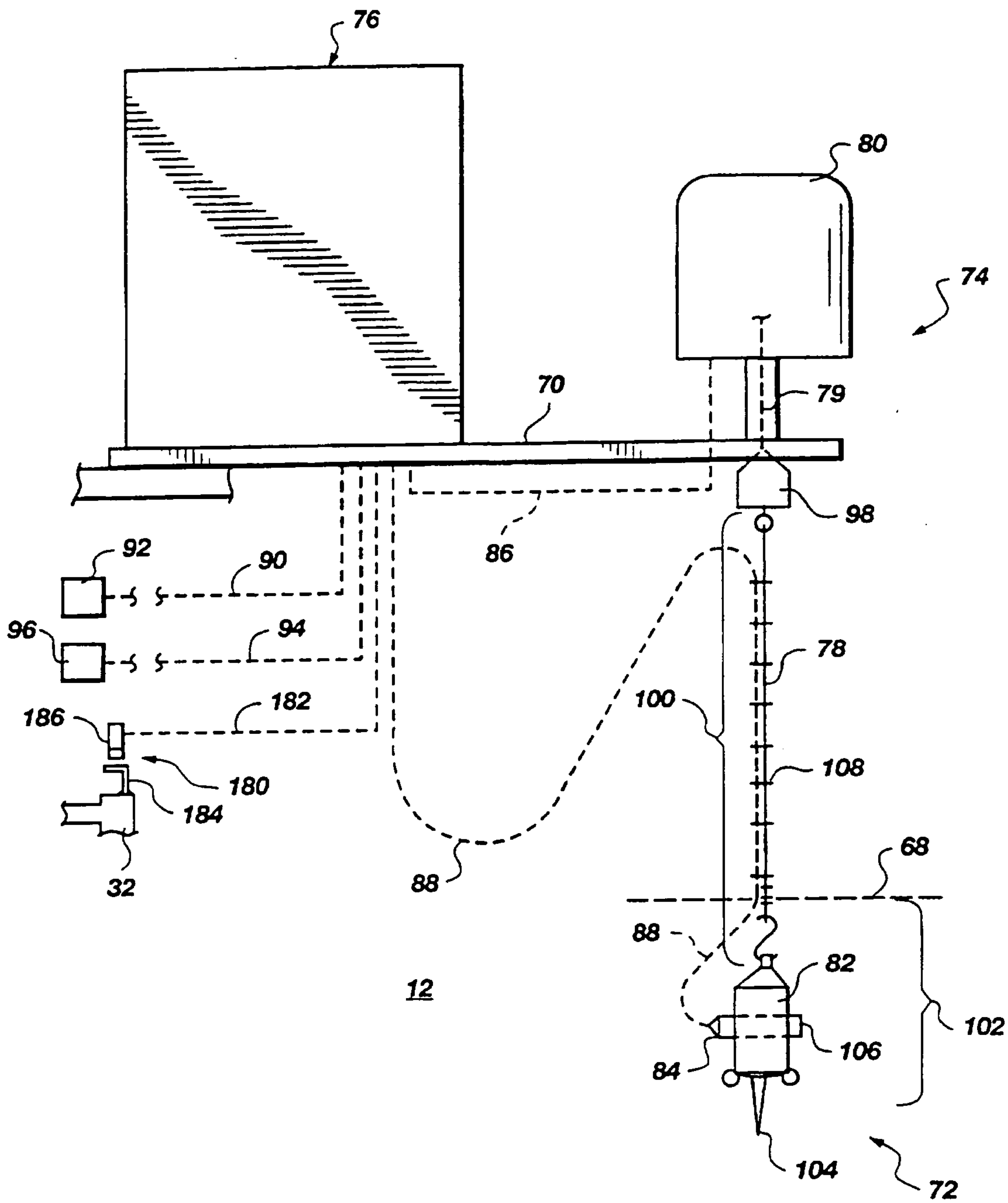
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Fig. 2

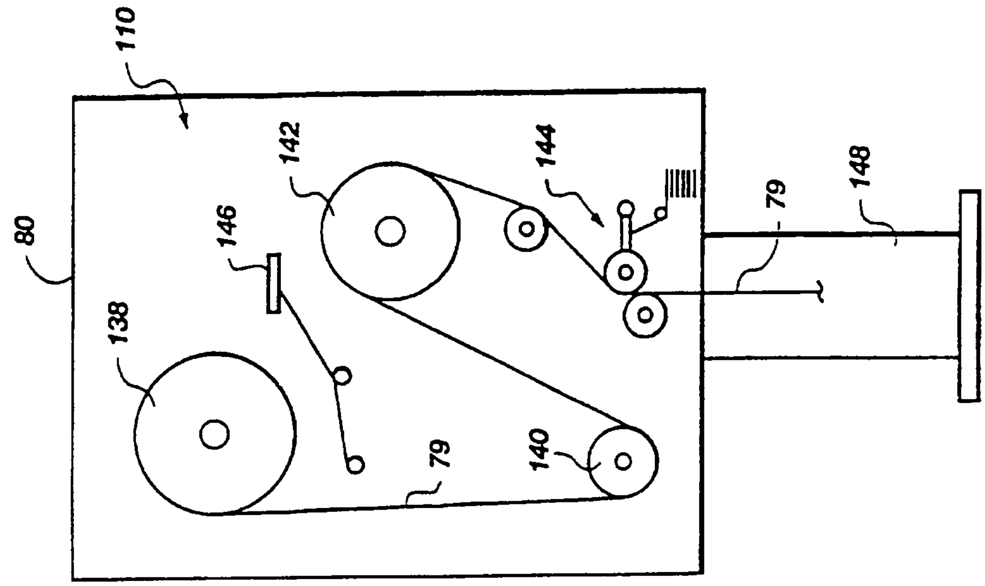
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Fig. 4

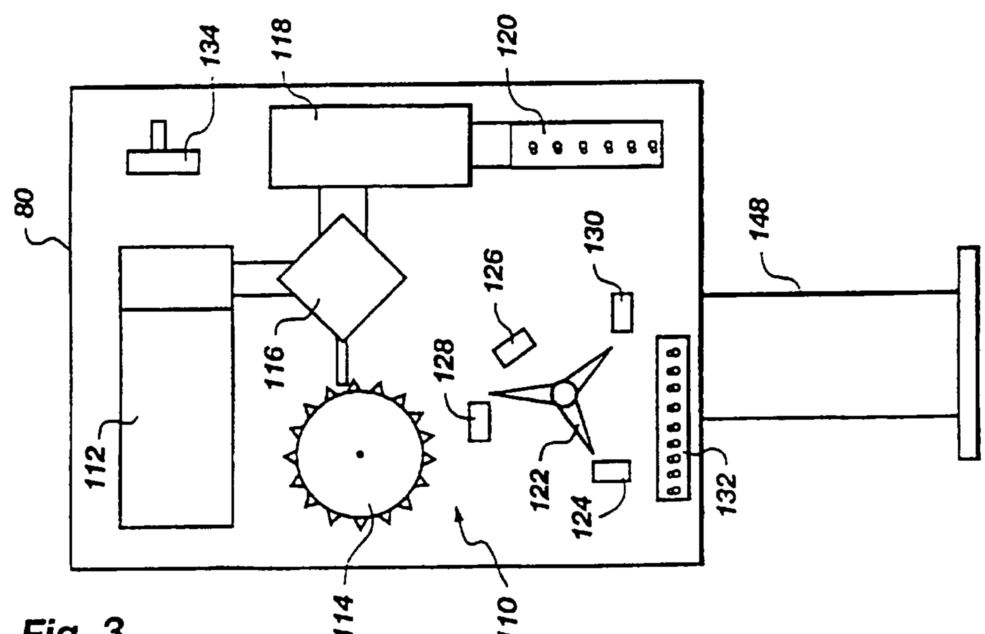
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Fig. 3

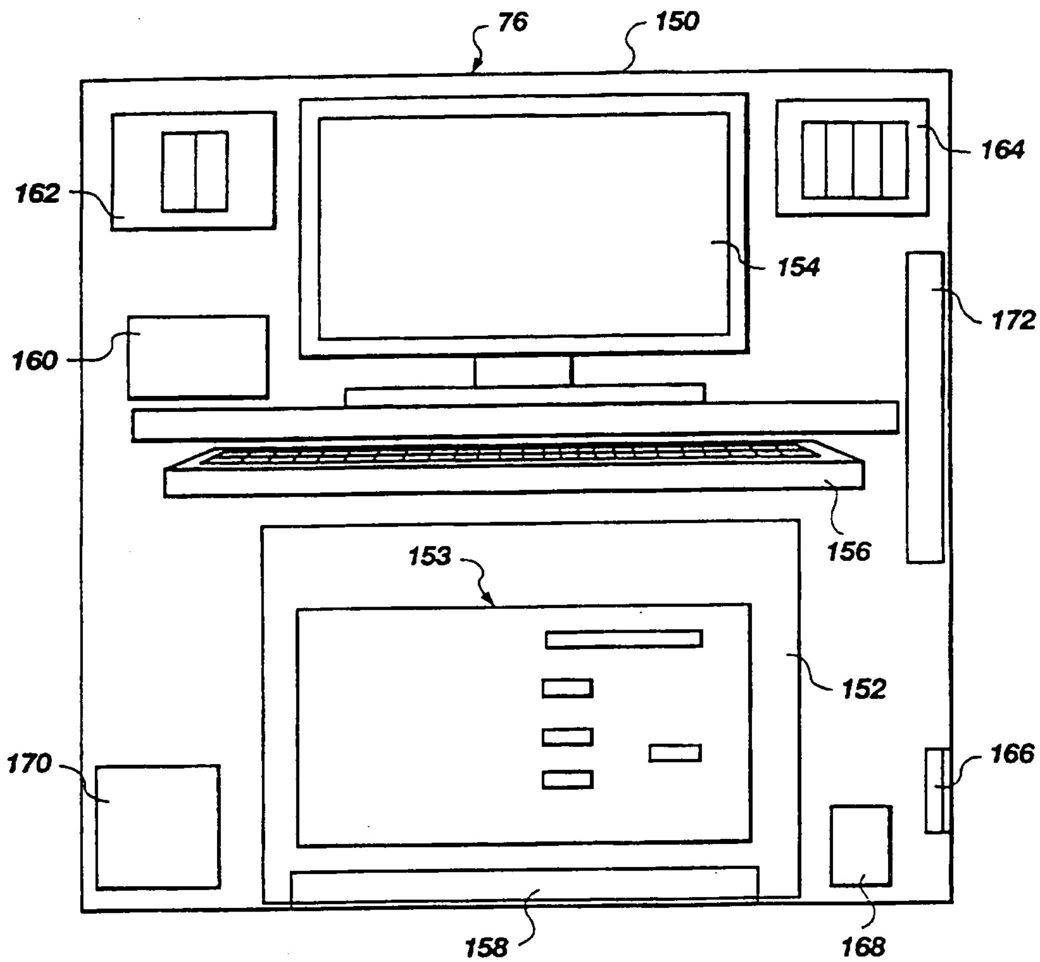
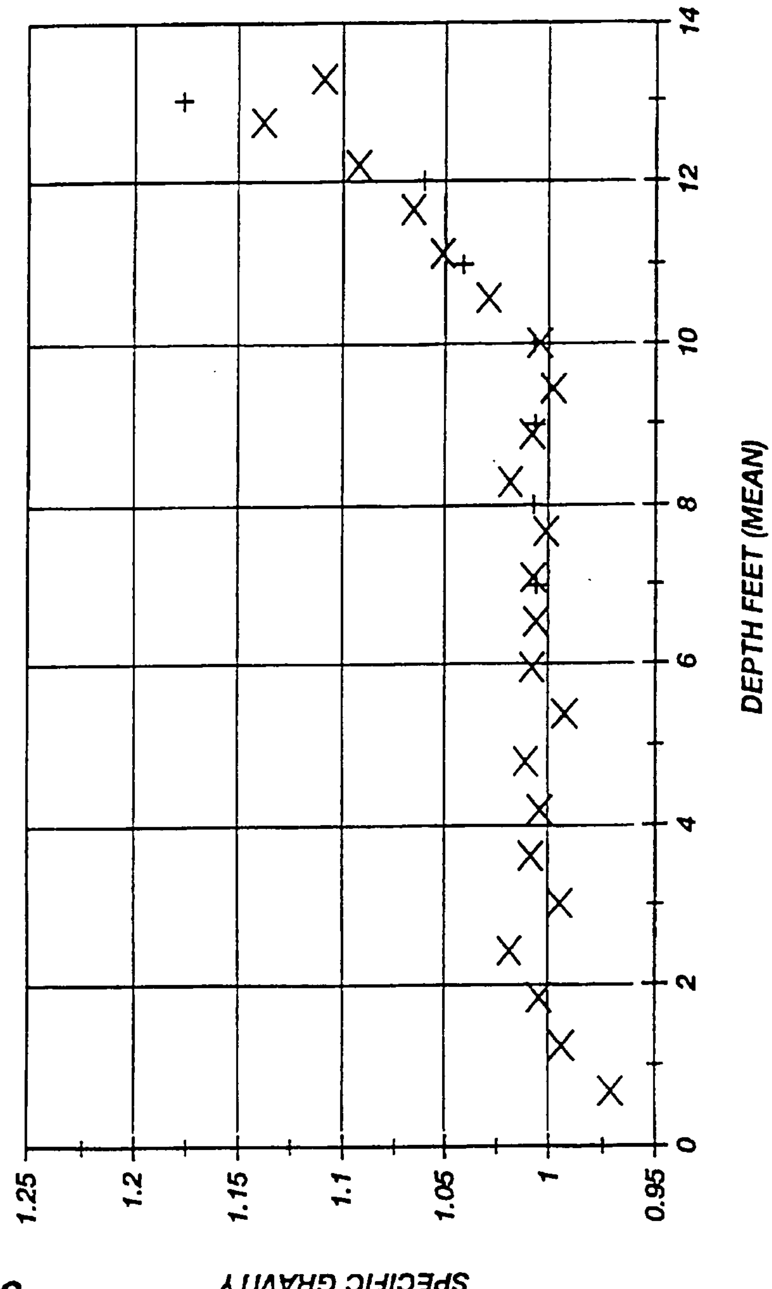


Fig. 5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1.2
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1.05
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0.95

Fig. 6

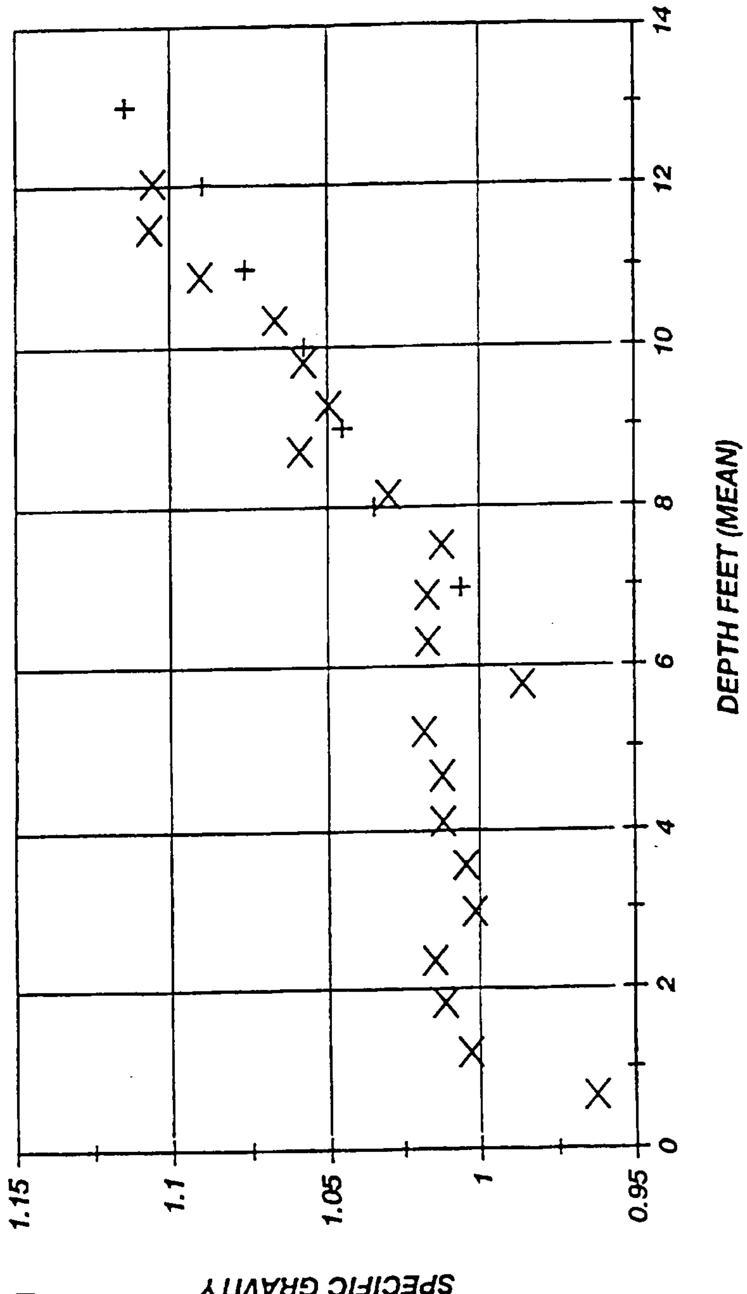
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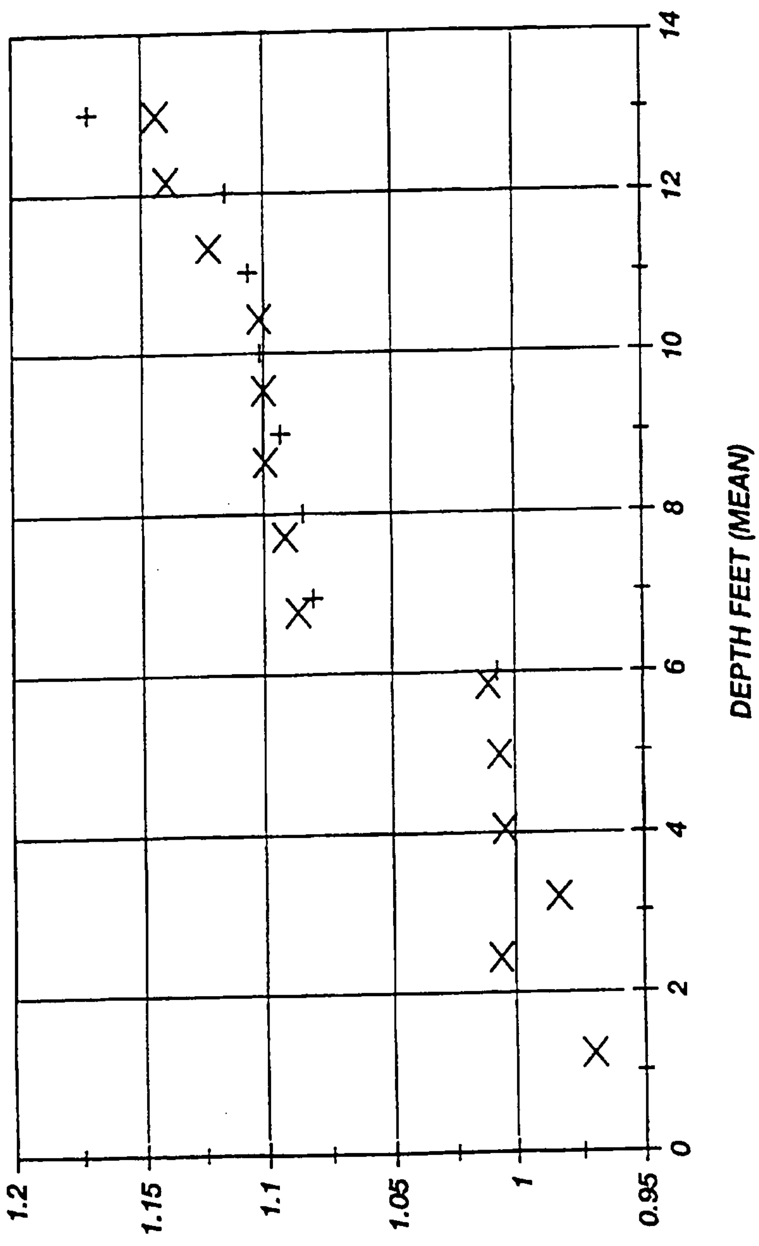
Fig. 7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SPECIFIC GRAVITY

Fig. 8